

Measurement of light mesons at RHIC by PHENIX experiment

Maxim Naglis
for the PHENIX collaboration



1 Motivation

2 PHENIX detector

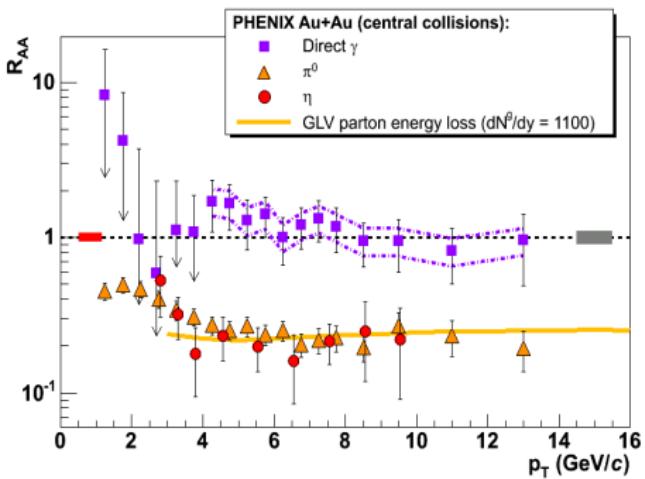
3 Results:

- Search for the onset of jet quenching
- Light mesons transverse momentum spectra
- Particle ratios
- Nuclear modification factors in Au+Au and d+Au

4 Summary

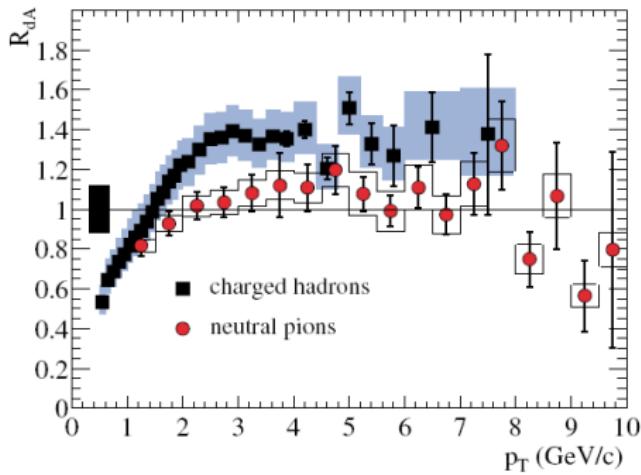
Motivation: the onset of jet quenching

Au+Au @ 200 GeV



Phys. Rev. Lett. 96, 202301 (2006)

d+Au @ 200 GeV



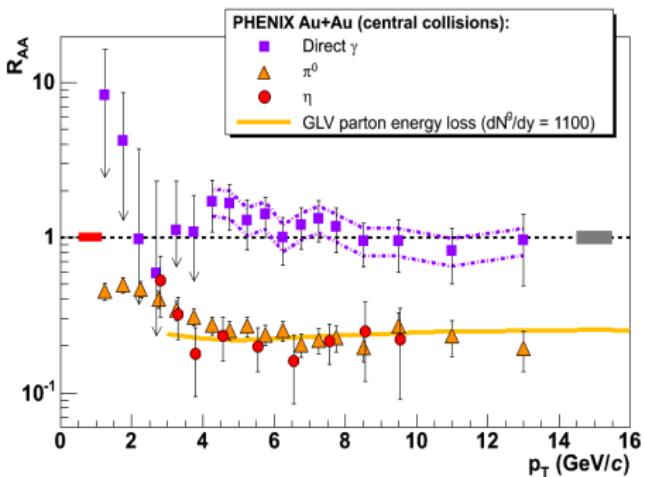
Phys. Rev. Lett. 91 072303 (2003)

- Strong suppression of high p_T hadrons in Au+Au collisions at $\sqrt{s_{NN}} = 130$, 200 and 62.4 GeV
- Direct photons are not suppressed
- No suppression in d+Au collisions

Suppression is a final state and hot matter effect.

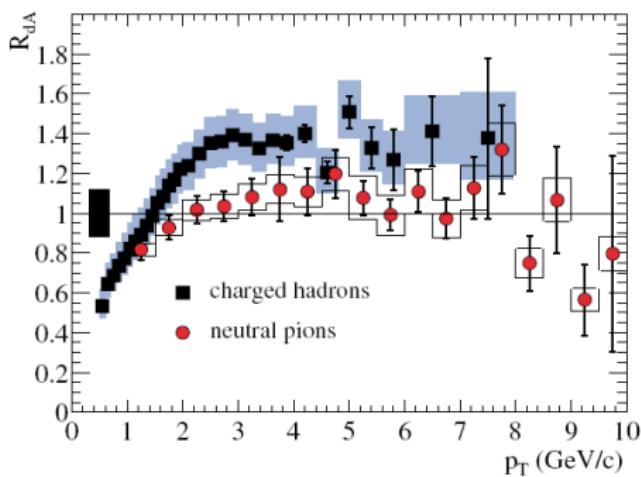
Motivation: the onset of jet quenching

Au+Au @ 200 GeV



Phys. Rev. Lett. 96, 202301 (2006)

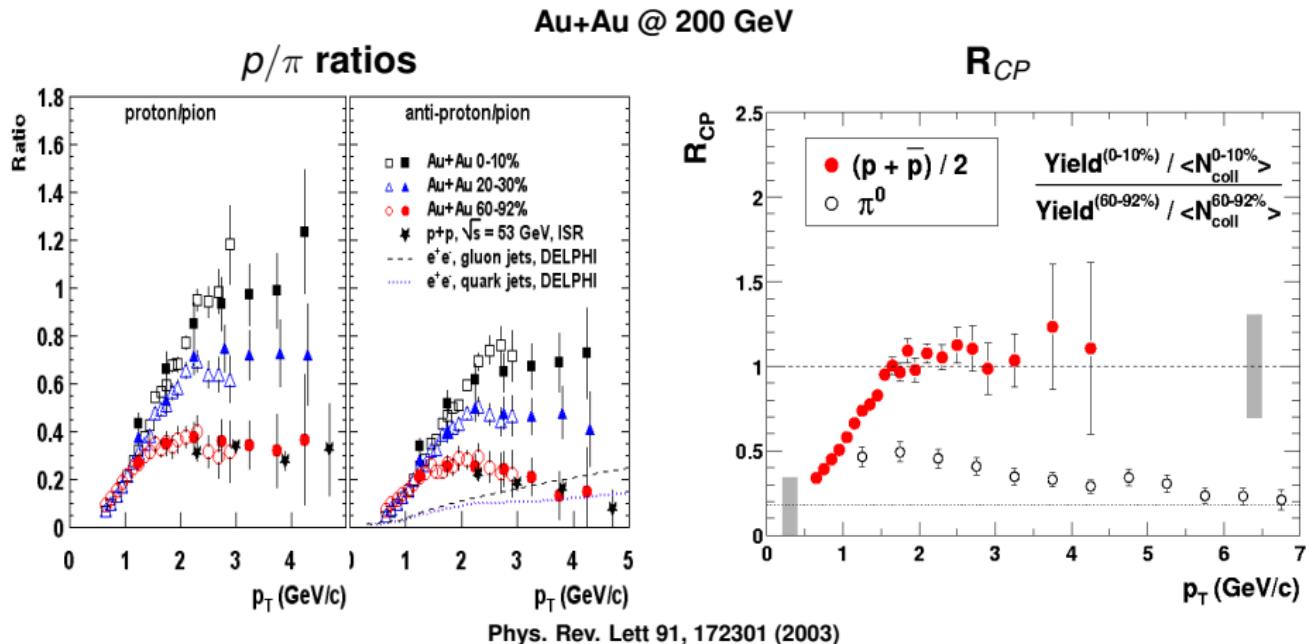
d+Au @ 200 GeV



Phys. Rev. Lett. 91 072303 (2003)

- Strong suppression of high p_T hadrons in Au+Au collisions at $\sqrt{s_{NN}} = 130, 200 \text{ GeV}$
 - Direct photons
 - No suppression at low p_T
- Systematic measurements of R_{AA} in different collision systems and at different energies allow to test predictions and assumptions of jet quenching models

Motivation: the baryon "anomaly"

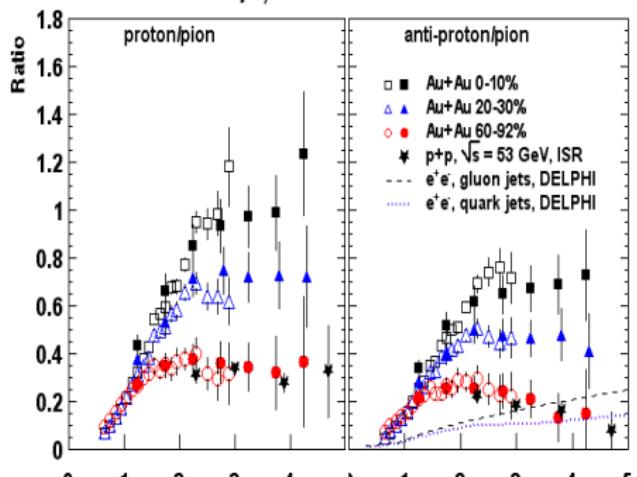


- Pions are suppressed in central Au+Au events at 200 GeV
 - No suppression seen for 2-4 GeV/c protons
 - The suppression patterns depend on particle species

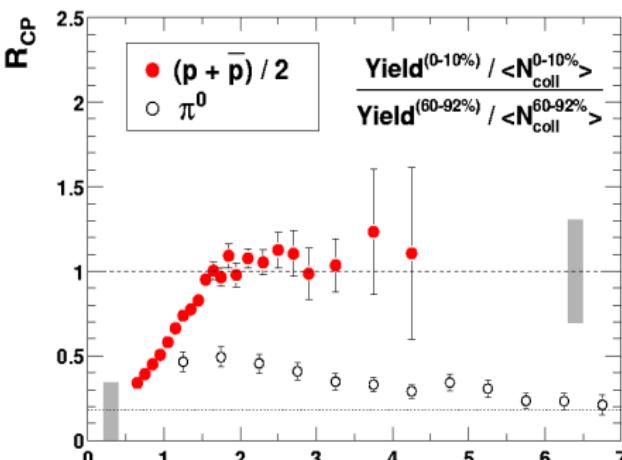
Motivation: the baryon "anomaly"

Au+Au @ 200 GeV

p/π ratios



R_{CP}

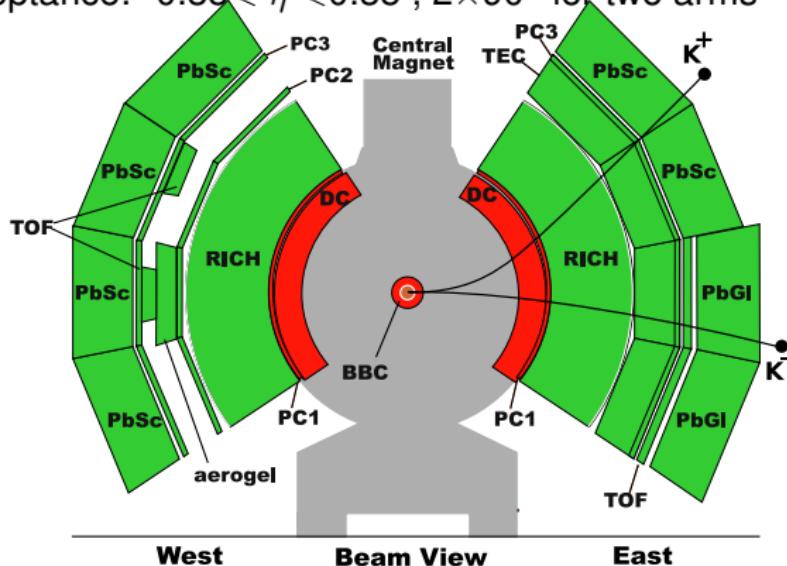


Systematic measurements for different particles needed for understanding the particle production:

- identified particle spectra
- particle ratios
- nuclear modification factors

PHENIX detector

Acceptance: $-0.35 < \eta < 0.35$, $2 \times 90^\circ$ for two arms



Vertex: **BBC**

Tracking: **DC/PC1** Matching: **PC3**

e ID: Čerenkov light **RICH**, E-p matching **EmCal**

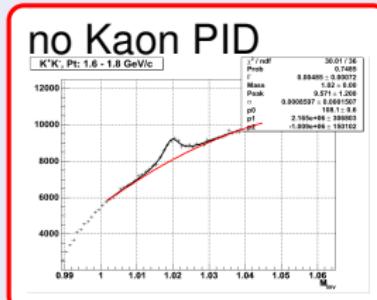
h ID: Time-of-flight **TOF, EmCal, Aerogel**

γ ID: Energy, shower profile **EmCal**

Trigger: **Min. bias: BBC** γ : **EmCal** **e**: **RICH,EmCal**

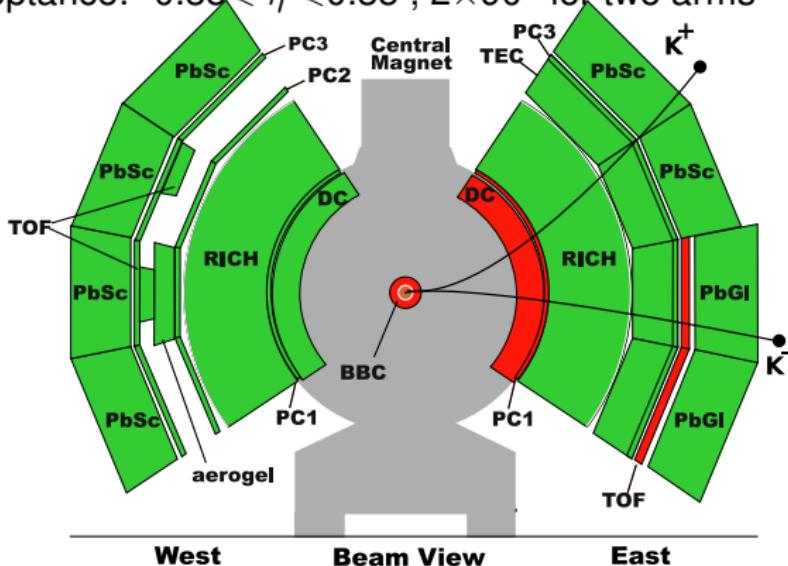
Decays under study

- $\phi \rightarrow K^+ K^-$ (no PID)



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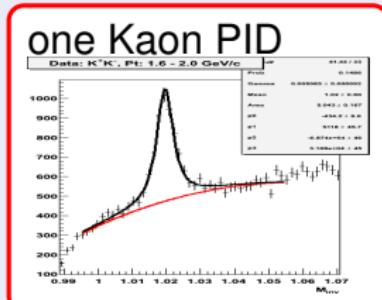
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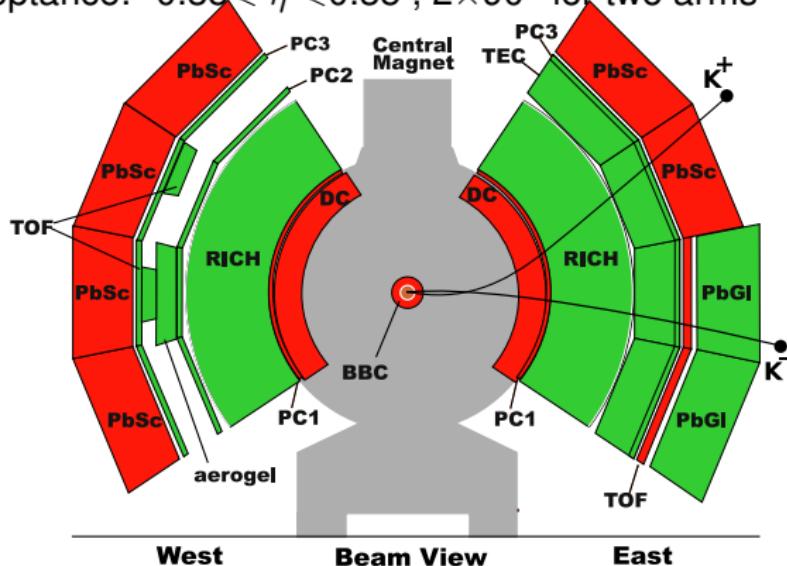
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- $\phi \rightarrow K^+ K^-$ (no PID)
- $\phi \rightarrow K^+ K^-$ (one Kaon PID)



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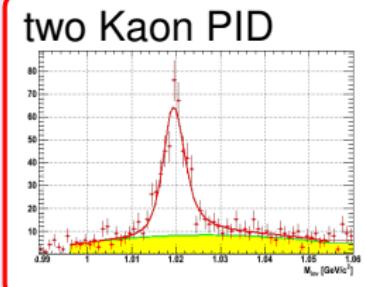
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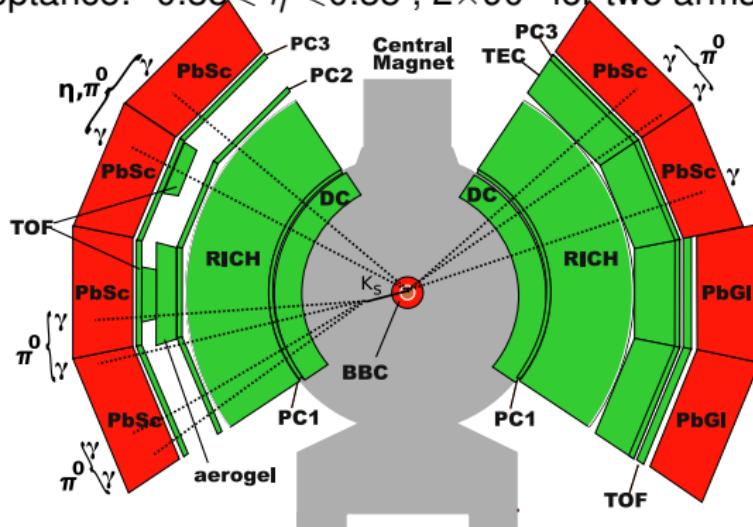
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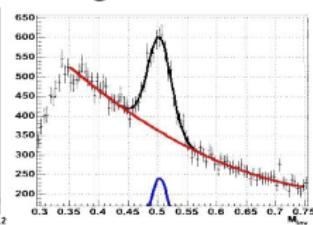
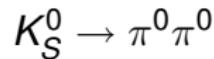
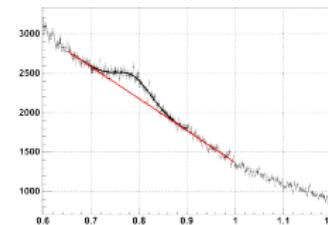
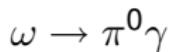
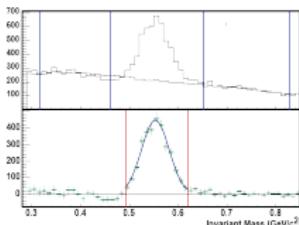
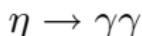
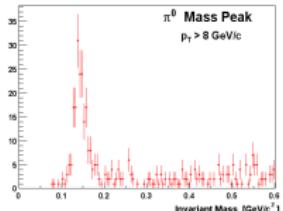
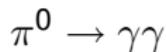
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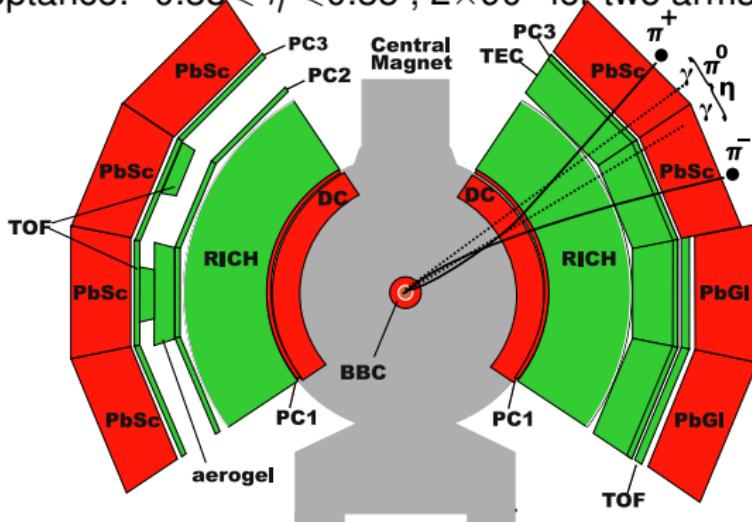
Decays under study

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(no PID)
- $\phi \rightarrow K^+ K^-$
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- $\phi \rightarrow K^+ K^-$
(two Kaon PID)
- $\pi^0 \rightarrow \gamma\gamma$
- $\eta \rightarrow \gamma\gamma$
- $\omega \rightarrow \pi^0 \gamma$
- $K_S^0 \rightarrow \pi^0 \pi^0$



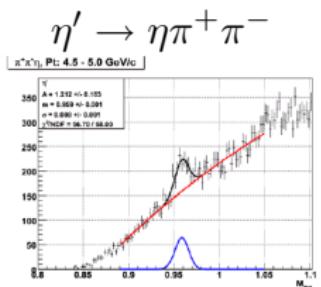
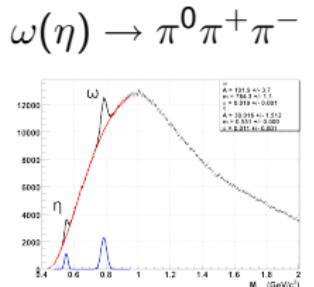
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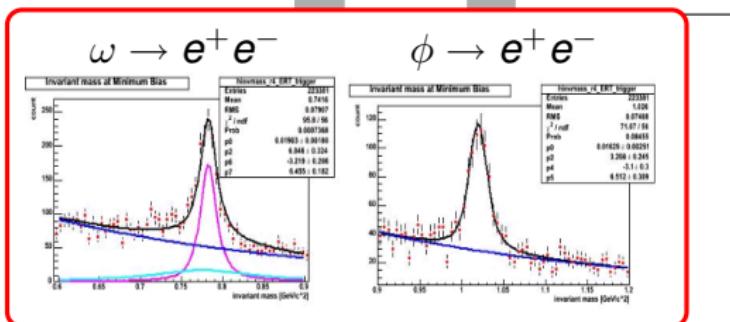
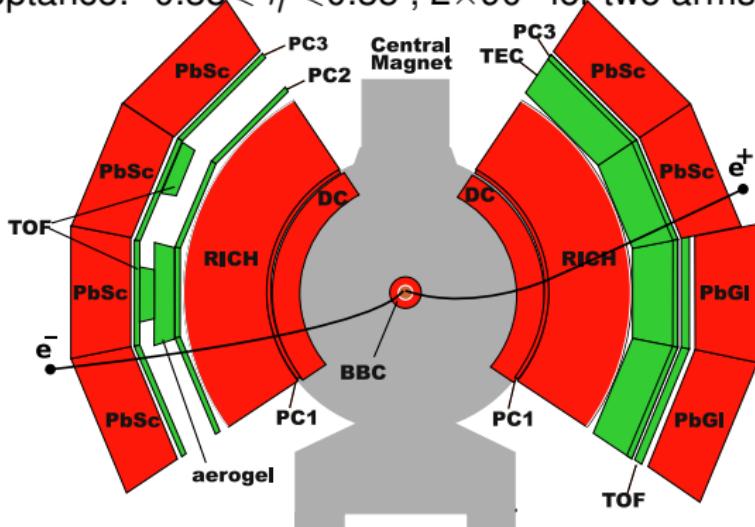
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- $\pi^0 \rightarrow \gamma\gamma$
- $\eta \rightarrow \gamma\gamma$
- $\omega \rightarrow \pi^0 \gamma$
- $K_S^0 \rightarrow \pi^0 \pi^0$
- $\eta \rightarrow \pi^0 \pi^+ \pi^-$
- $\omega \rightarrow \pi^0 \pi^+ \pi^-$
- $\eta' \rightarrow \eta \pi^+ \pi^-$



PHENIX detector

Acceptance: $-0.35 < \eta < 0.35$, $2 \times 90^\circ$ for two arms

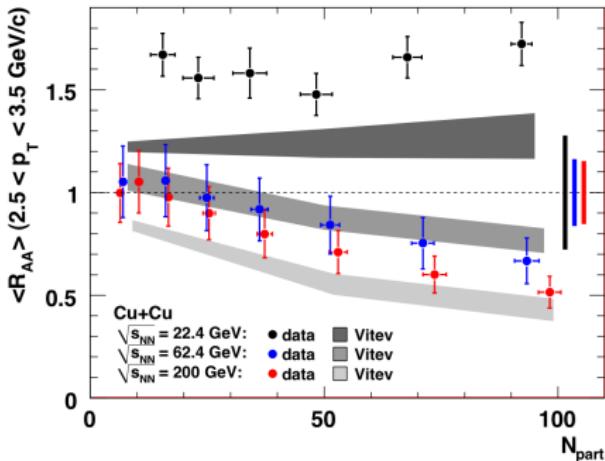
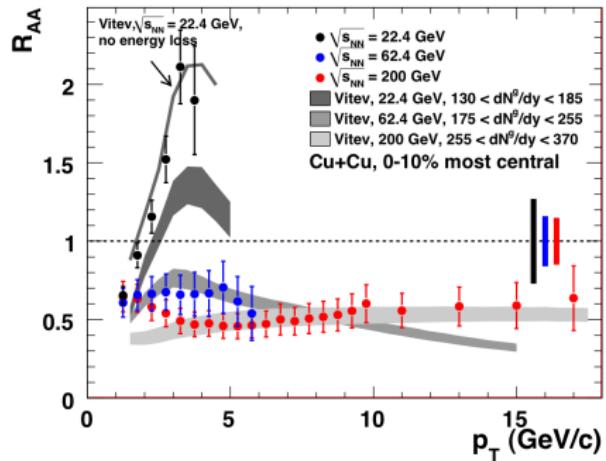


Decays under study

- $\phi \rightarrow K^+ K^-$
(no PID)
- $\phi \rightarrow K^+ K^-$
(one Kaon PID)
- $\phi \rightarrow K^+ K^-$
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- $\pi^0 \rightarrow \gamma\gamma$
 $\eta \rightarrow \gamma\gamma$
 $\omega \rightarrow \pi^0 \gamma$
 $K_S^0 \rightarrow \pi^0 \pi^0$
- $\eta \rightarrow \pi^0 \pi^+ \pi^-$
 $\omega \rightarrow \pi^0 \pi^+ \pi^-$
 $\eta' \rightarrow \eta \pi^+ \pi^-$
- $\phi \rightarrow e^+ e^-$
 $\omega \rightarrow e^+ e^-$

Search for the onset of jet quenching

R_{AA} of π^0 meson in Cu+Cu collisions at 22.4, 62.4 and 200 GeV

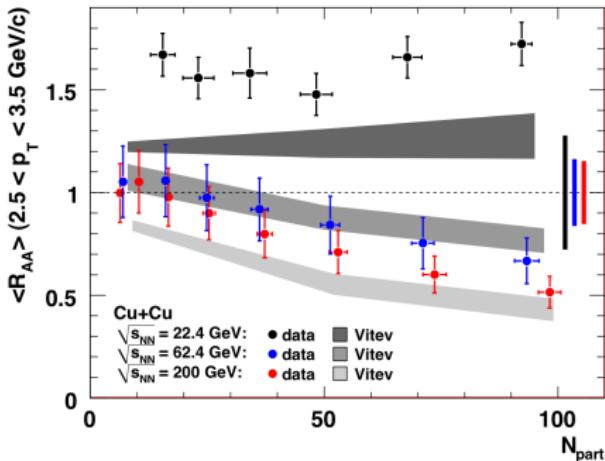
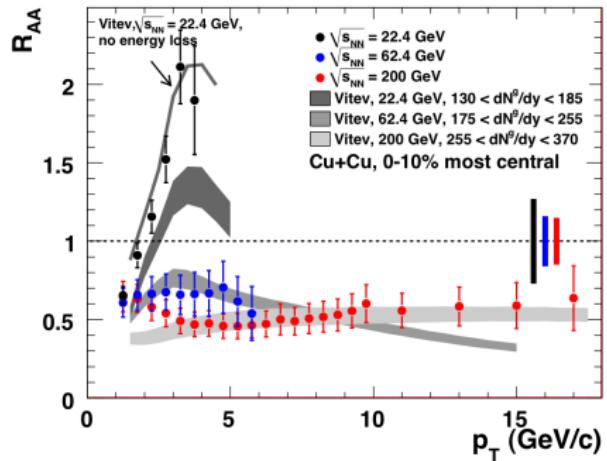


arXiv:0801.4555 [nucl-ex]

- **At 62.4, 200 GeV:** parton energy loss calculations reproduce p_T dependence for $p_T > 3$ GeV
- **At 22.4 GeV:** no suppression, enhancement consistent with Cronin effect in p+A, weakly dependent on centrality

Search for the onset of jet quenching

R_{AA} of π^0 meson in Cu+Cu collisions at 22.4, 62.4 and 200 GeV

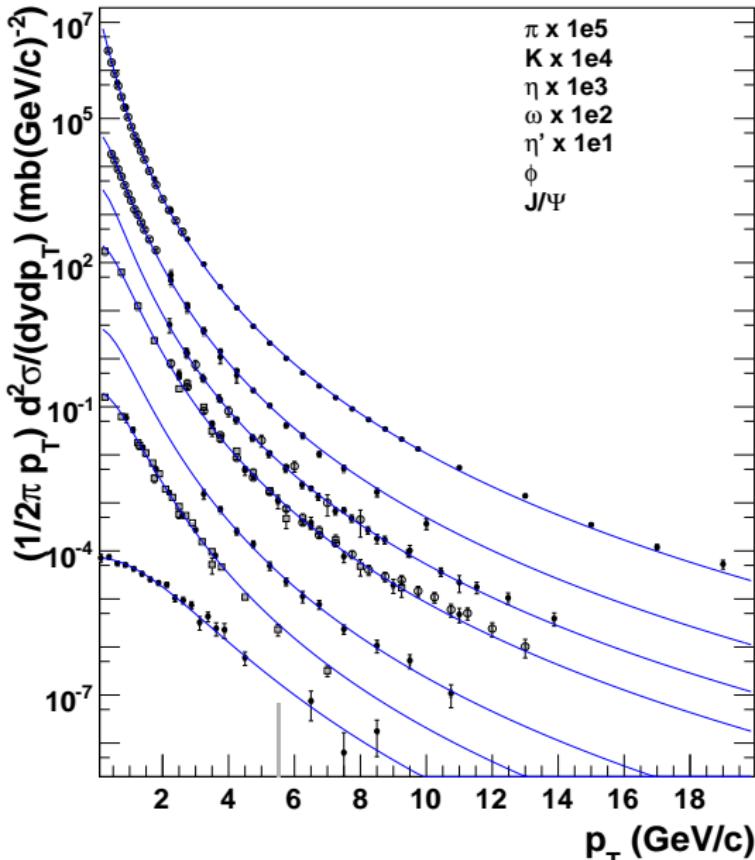


arXiv:0801.4555 [nucl-ex]

- At 62.4, 200 GeV: parton energy loss calculations reproduce p_T
Onset of parton energy loss is between 22.4 and 62.4 GeV in Cu+Cu

Cronin effect in p+A, weakly dependent on centrality

Mesons spectra in p+p collisions at 200 GeV



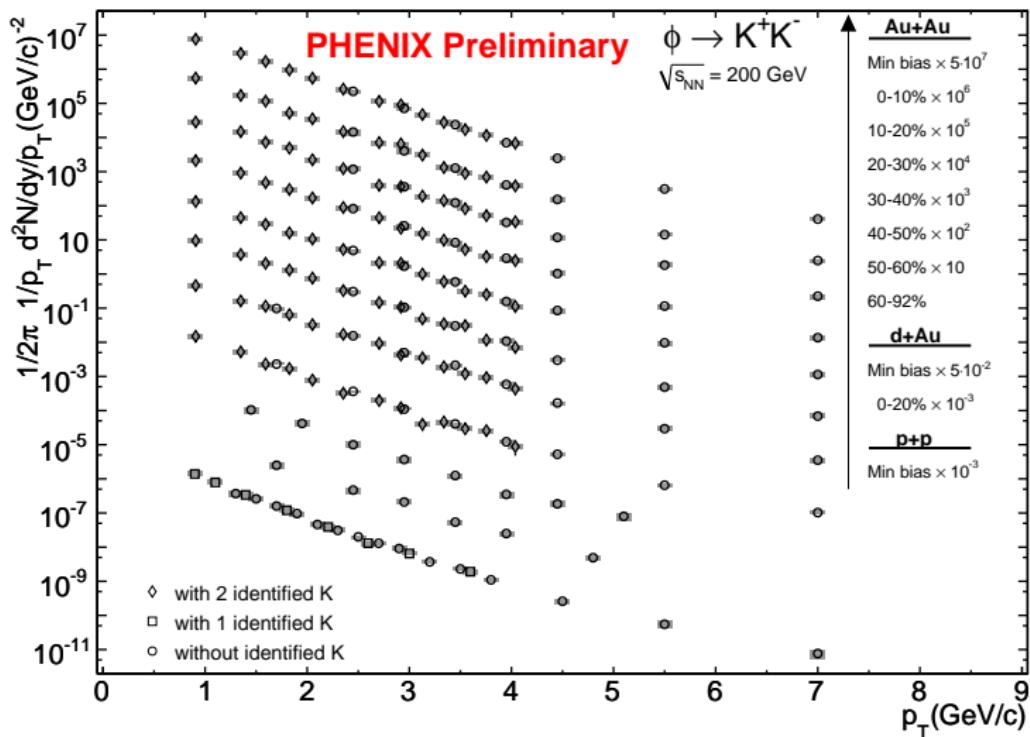
Compilation of PHENIX published and preliminary results.

Impressive set of meson measurements: wide p_T range, multiple decay modes.

Solid baseline is ready for comparison to A+A data.

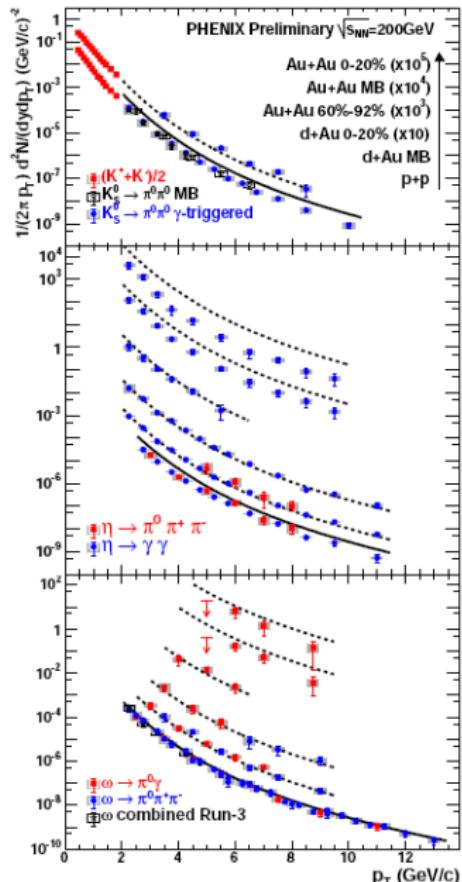
Different symbols correspond to different measurements (decay channel, technique).

$\phi \rightarrow K^+K^-$ spectra



- Two independent analyses agree in Au+Au, two in p+p
- New solid p+p reference

ω , η , K_S^0 and η' spectra



K_S^0 meson measured in p+p and d+Au.
Analysis in Au+Au ongoing.

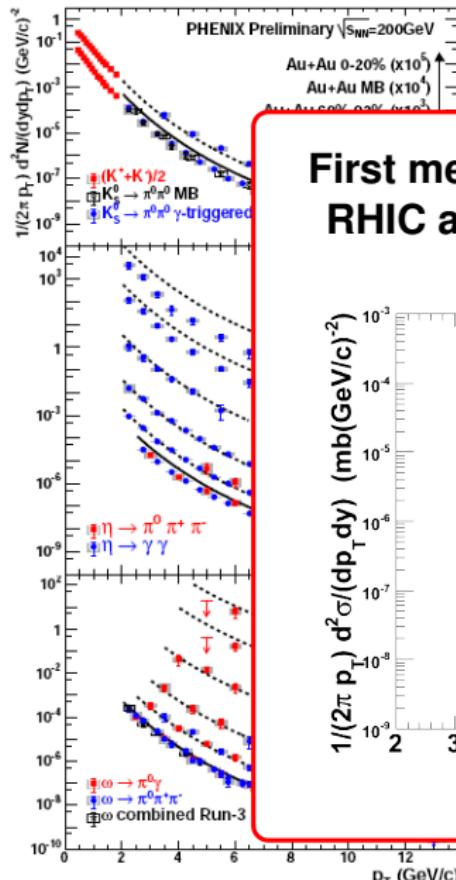
η meson measured at high p_T in p+p,
d+Au and Au+Au

In p+p and d+Au results of $\eta \rightarrow \gamma \gamma$ and
 $\eta \rightarrow \pi^0 \pi^+ \pi^-$ analyses agree well.

ω meson measured at high p_T in p+p,
d+Au and Au+Au

In p+p and d+Au results of $\omega \rightarrow \pi^0 \gamma$ and
 $\omega \rightarrow \pi^0 \pi^+ \pi^-$ analyses agree well.

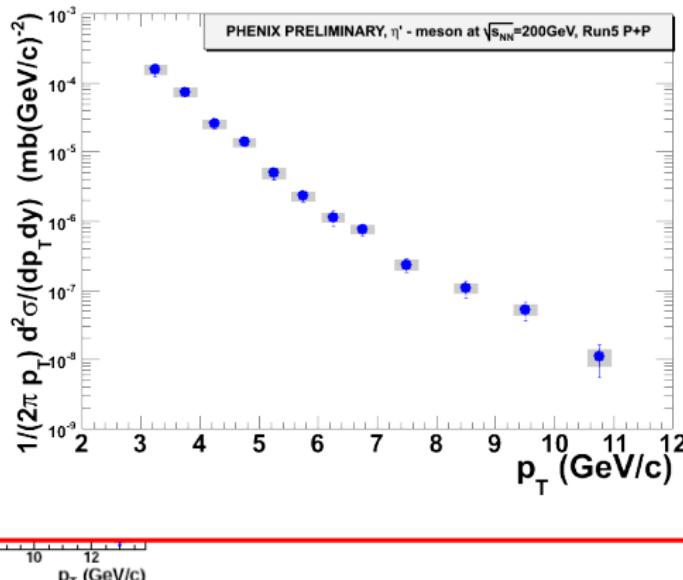
ω , η , K_S^0 and η' spectra



K_S^0 meson measured in p+p and d+Au.
Analysis in Au+Au ongoing.

New

First measurement of $\eta' \rightarrow \eta \pi^+ \pi^-$ at
RHIC at high p_T in p+p by PHENIX



p_T in p+p,

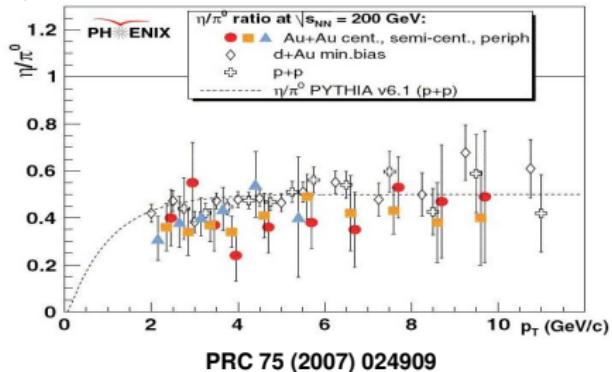
$\eta \rightarrow \gamma \gamma$ and
e well.

p_T in p+p,

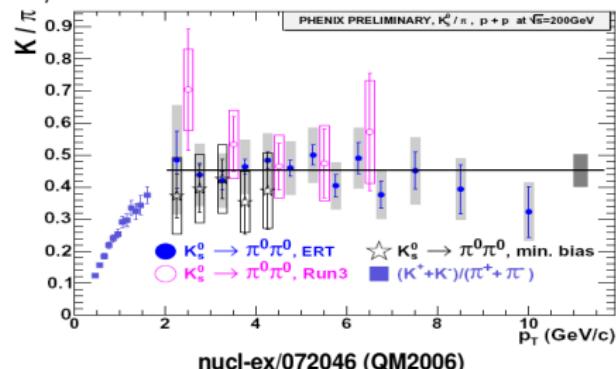
$\omega \rightarrow \pi^0 \gamma$ and
e well.

Particle ratios

η/π^0



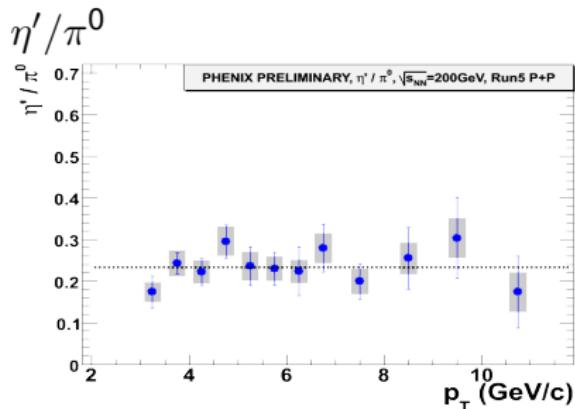
K/π^0



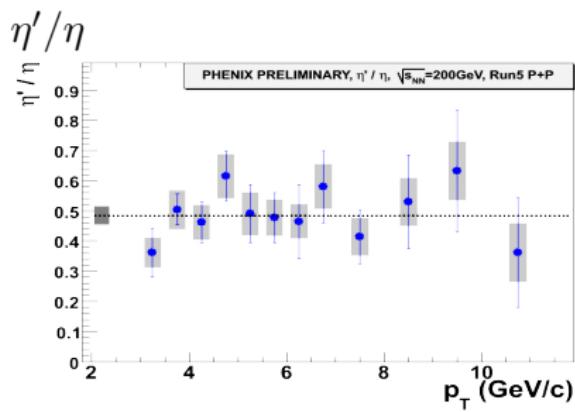
Observation: meson to meson ratios are flat above $p_T = 2.5$ GeV/c

$\eta/\pi^0, K/\pi^0$

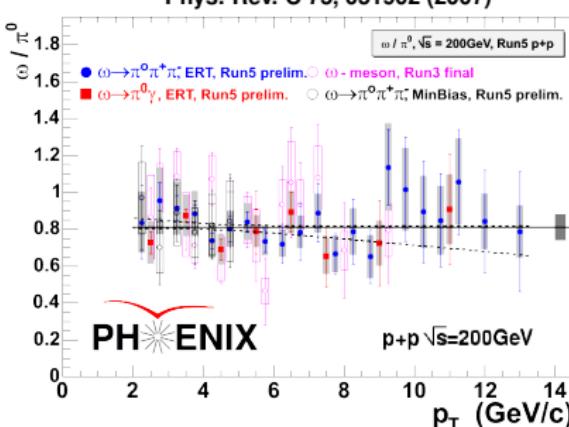
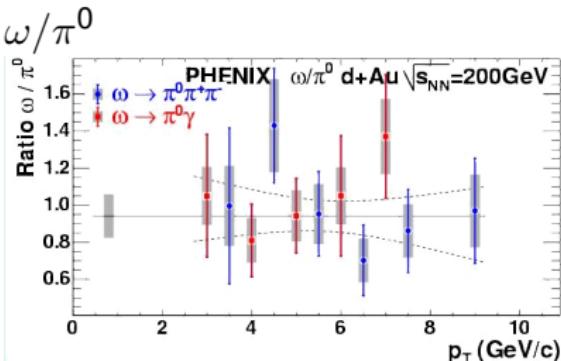
Particle ratios



Observation: meson to meson ratios are flat above $p_T = 2.5$ GeV/c
 $\eta/\pi^0, K/\pi^0, \eta'/\pi^0, \eta'/\eta$



Particle ratios



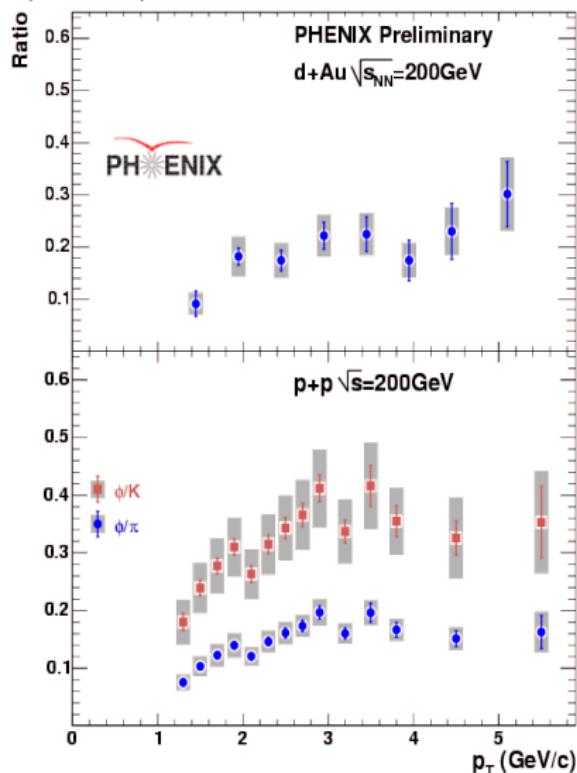
nucl-ex/0702046 (QM2006)

Observation: meson to meson ratios are flat above $p_T = 2.5 \text{ GeV}/c$

$\eta/\pi^0, K/\pi^0, \eta'/\pi^0, \eta'/\eta, \omega/\pi^0$

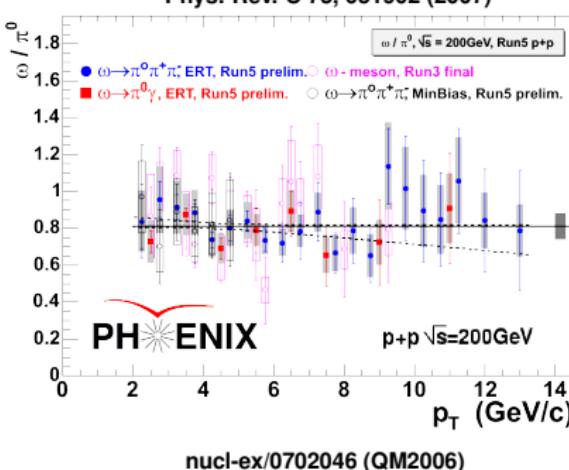
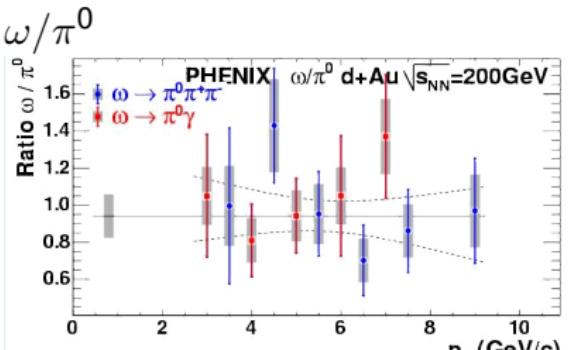
Particle ratios

$\phi/\pi^0, \phi/K$



Observation: meson to meson ratios are flat above $p_T = 2.5$ GeV/c
 $\eta/\pi^0, K/\pi^0, \eta'/\pi^0, \eta'/\eta, \omega/\pi^0, \phi/\pi^0, \phi/K$

Particle ratios



Observation: meson to meson ratios are flat above $p_T = 2.5$ GeV/c

η/π^0

in p+p:

$0.48 \pm 0.02(\text{stat}) \pm 0.02(\text{syst})$

in d+Au:

$0.47 \pm 0.02(\text{stat}) \pm 0.02(\text{syst})$

K_S^0/π^0

in p+p:

$0.45 \pm 0.01(\text{stat}) \pm 0.05(\text{syst})$

in d+Au:

$0.58 \pm 0.06(\text{stat}) \pm 0.05(\text{syst})$

ω/π^0

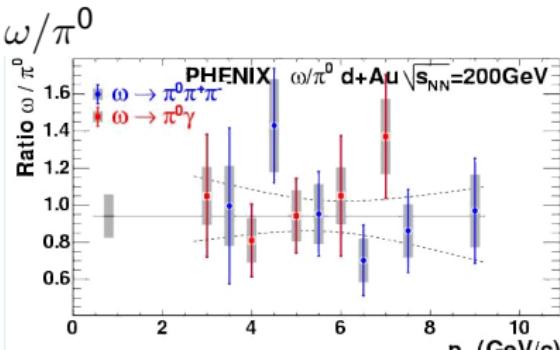
in p+p:

$0.81 \pm 0.02(\text{stat}) \pm 0.07(\text{syst})$

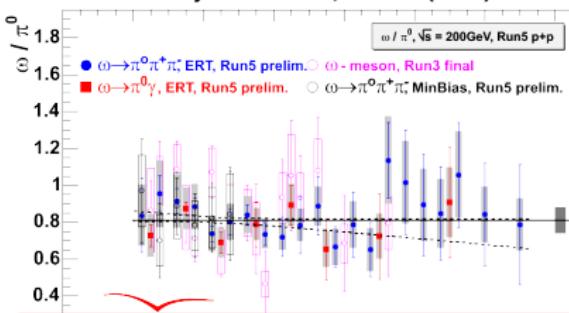
in d+Au:

$0.94 \pm 0.08(\text{stat}) \pm 0.12(\text{syst})$

Particle ratios



Phys. Rev. C 75, 051902 (2007)



Observation: meson to meson ratios are flat above $p_T = 2.5$ GeV/c
 $\eta/\pi^0, K/\pi^0, \eta'/\pi^0, \eta'/\eta, \omega/\pi^0, \phi/\pi^0, \phi/K$
 η/π^0

in $p+p$:

$0.48 \pm 0.02(\text{stat}) \pm 0.02(\text{syst})$

in $d+Au$:

$0.47 \pm 0.02(\text{stat}) \pm 0.02(\text{syst})$

K_S^0/π^0

in $p+p$:

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in $d+Au$:

$0.58 \pm 0.06(\text{stat}) \pm 0.05(\text{syst})$

ω/π^0

in $p+p$:

- Same slope at high p_T for all mesons!
- Cold nuclear matter does not affect jet fragmentation.

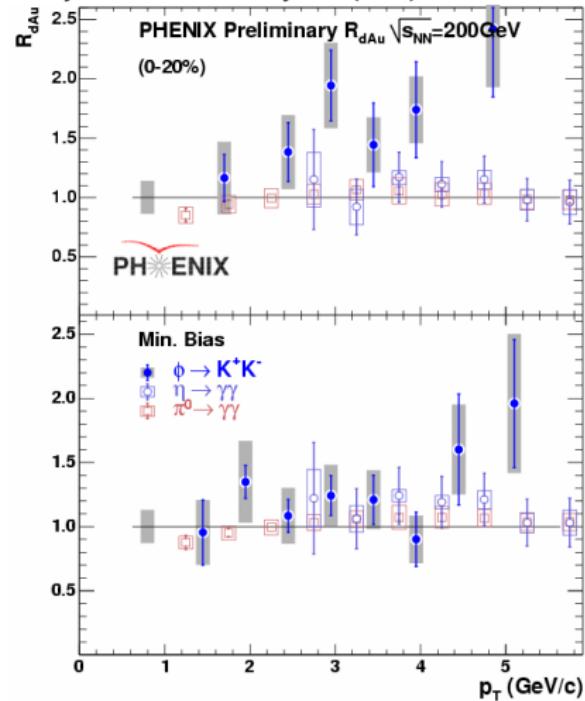
Nucl-Ex/0702040 (QM2008)

Nuclear modification factors

in d+Au at 200 GeV

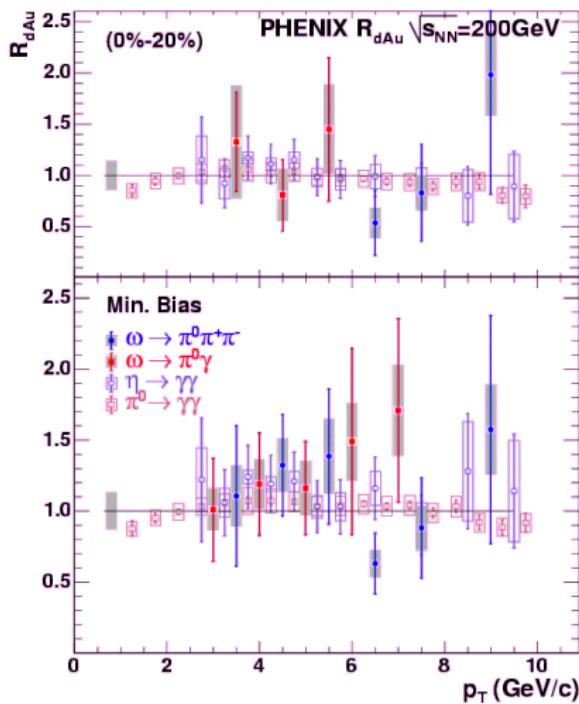
ϕ, η, π^0

J. Phys. G: Nucl. Part. Phys. 35 (2008) 044030



ω, η, π^0

Phys. Rev. C 75, 051902 (2007)

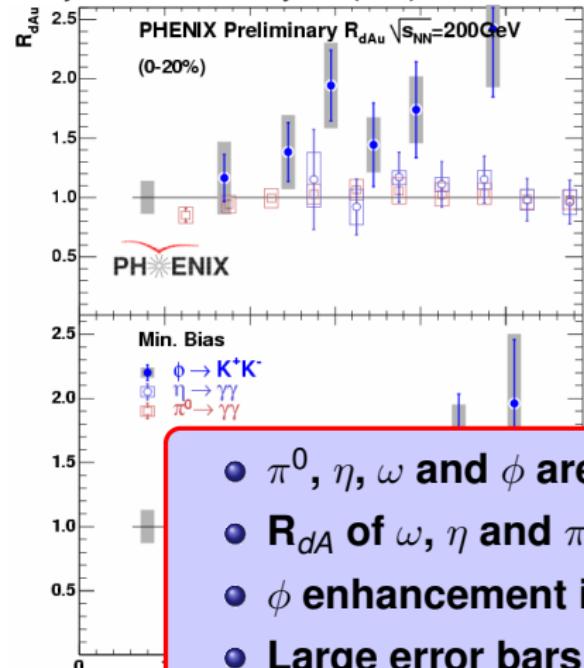


Nuclear modification factors

in d+Au at 200 GeV

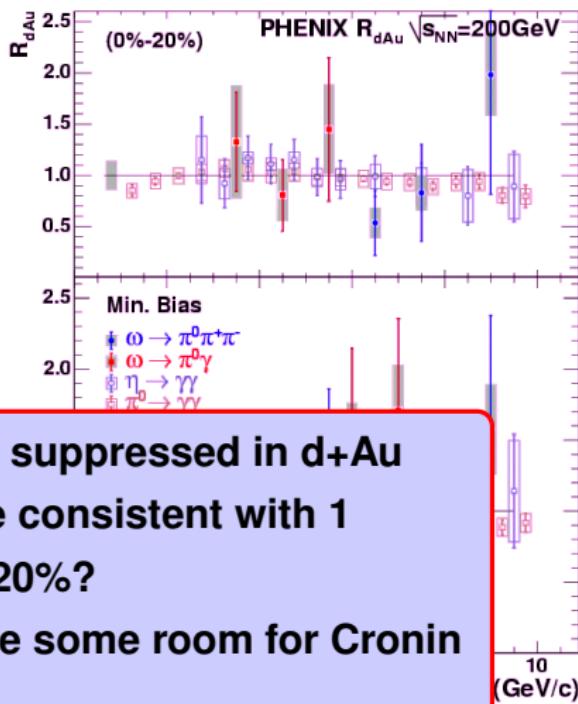
ϕ, η, π^0

J. Phys. G: Nucl. Part. Phys. 35 (2008) 044030



ω, η, π^0

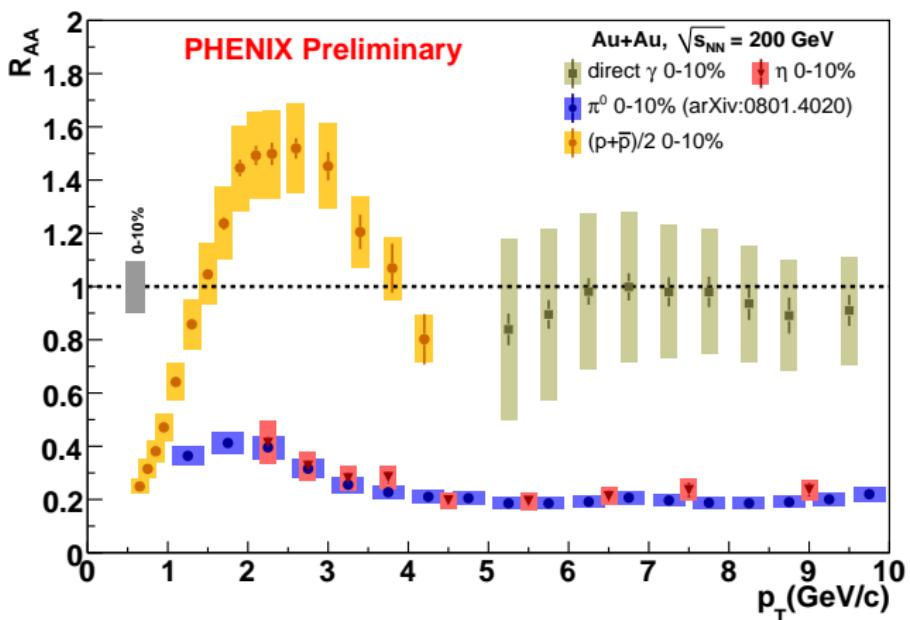
Phys. Rev. C 75, 051902 (2007)



- π^0, η, ω and ϕ are not suppressed in d+Au
- R_{dA} of ω, η and π^0 are consistent with 1
- ϕ enhancement in 0-20%?
- Large error bars leave some room for Cronin enhancement

Nuclear modification factors

in Au+Au at 200 GeV

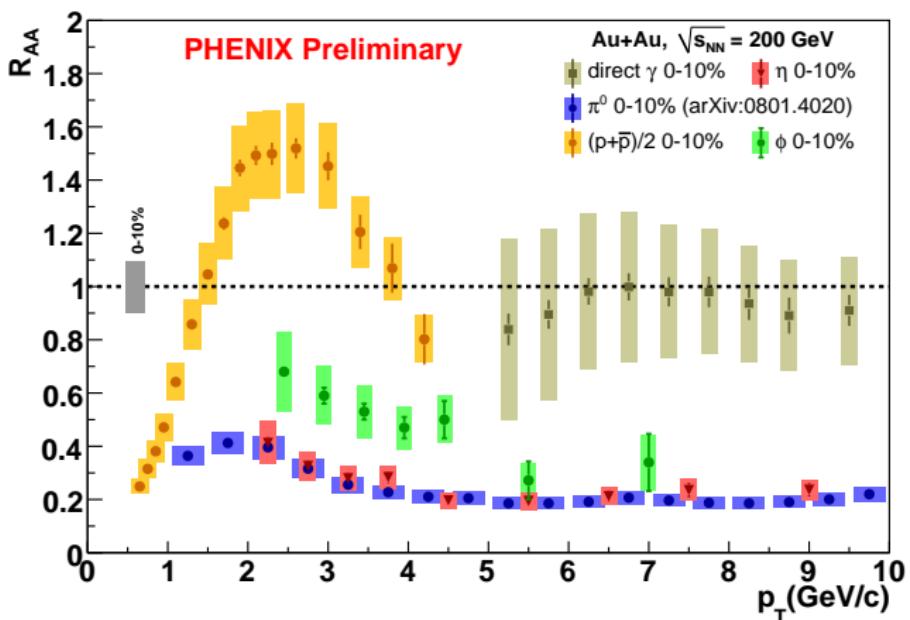


The common belief:

Hadron suppression patterns do not depend on the mass of the particles, but they are sensitive to the number of valence quarks.

Nuclear modification factors

in Au+Au at 200 GeV

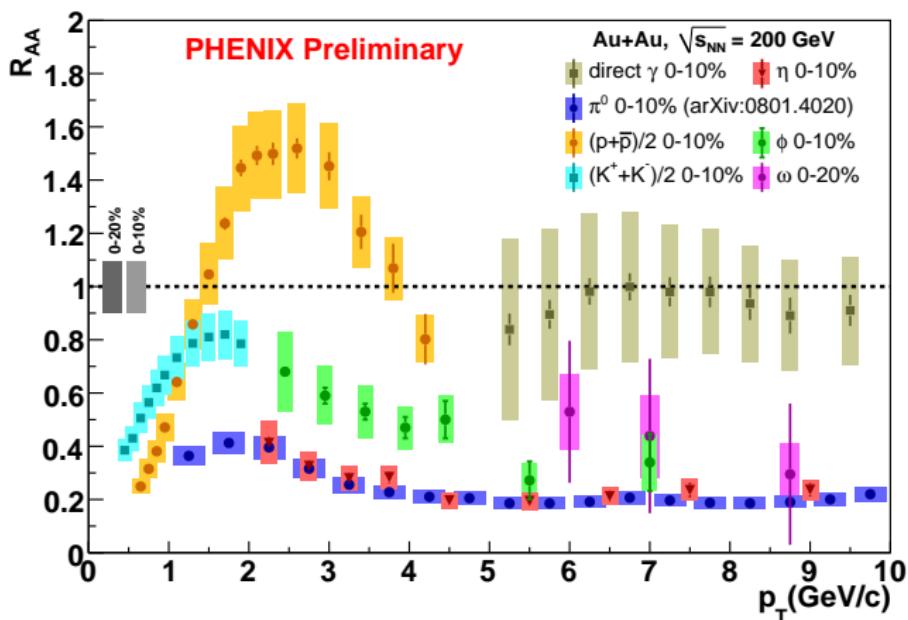


ϕ meson does not fit into common picture...

It is less suppressed than π^0 and η at intermediate p_T .
Does suppression depend on quark flavor composition?

Nuclear modification factors

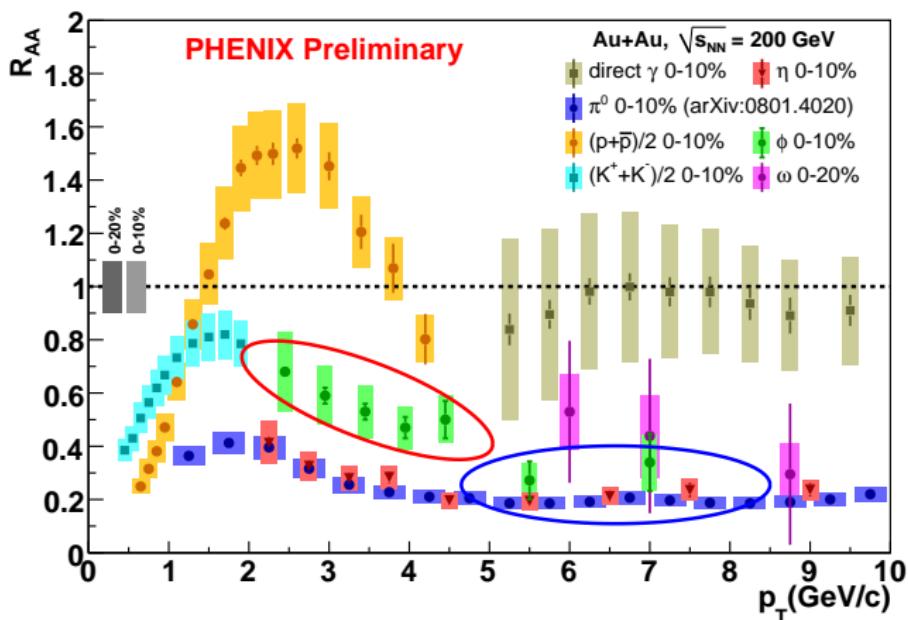
in Au+Au at 200 GeV



K and ω points are not conclusive.

Nuclear modification factors

in Au+Au at 200 GeV



At high p_T : π^0 , η , ϕ show similar suppression levels.

At intermediate p_T : ϕ meson suppression pattern is different as compared to η and π^0 .

Summary

PHENIX has measured π^0 , K , η , ω , η' , ϕ - mesons via multiple decay channels, over a broad range of transverse momentum in different collision systems.

Onset of parton energy loss is between 22.4 and 62.4 GeV in Cu+Cu.

For all mesons that PHENIX measures the baseline results ($p+p \sqrt{s} = 200$ GeV) exist in hadronic channels. Leptonic decay channels for ω and ϕ are being analyzed.

In $p+p$ and $d+Au$ all mesons show an universal behavior: same slopes at high p_T . Cold nuclear matter does not affect jet fragmentation.

No suppression is seen in $d+Au$, large error bars leave some room for Cronin enhancement.

In $Au+Au$ ϕ meson shows same suppression level as π^0 and η at high p_T and it is less suppressed than π^0 and η at intermediate p_T .
Does suppression depend on quark flavor composition?

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14 Countries; 69 Institutions



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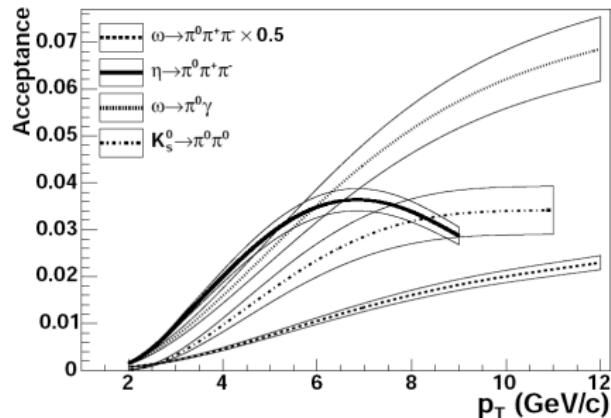
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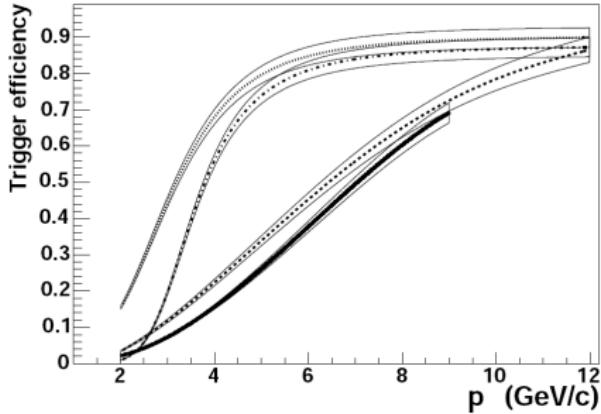
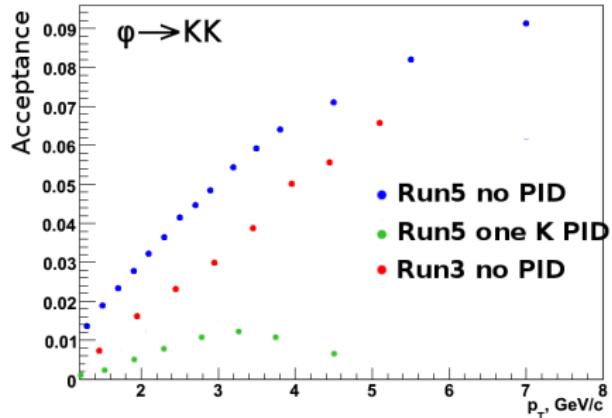
Vanderbilt University, Nashville, TN 37235, U.S.

BACKUPS

Acceptance and trigger

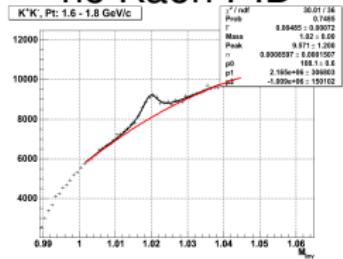


Because of the multi-particle final state even very high p_T are affected by the efficiency rising region

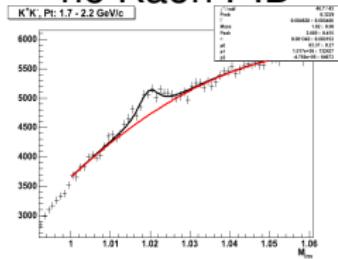


ϕ raw peaks

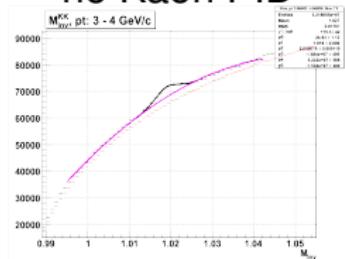
p+p @ 200 GeV
no Kaon PID



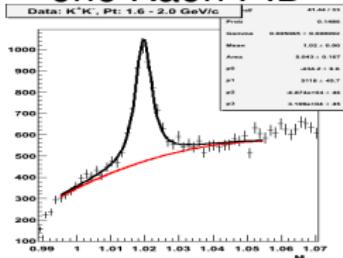
d+Au @ 200 GeV
no Kaon PID



Au+Au @ 200 GeV
no Kaon PID

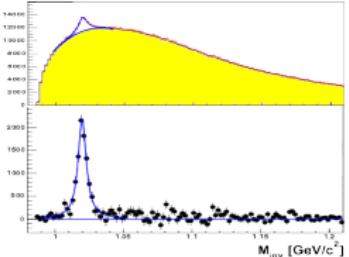


one Kaon PID



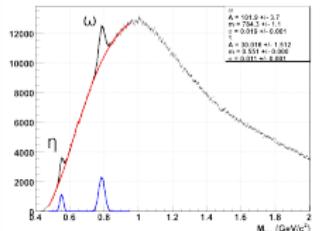
PHENIX measured ϕ up to 5 GeV/c in $d+Au$ and up to 7 GeV/c in $p+p$ and $Au+Au$ using **no PID** and **one Kaon PID** approaches

two Kaon PID

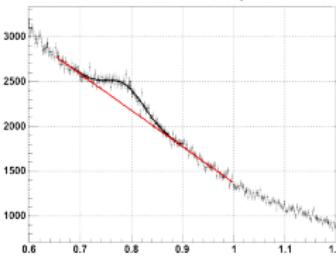


ω raw peaks

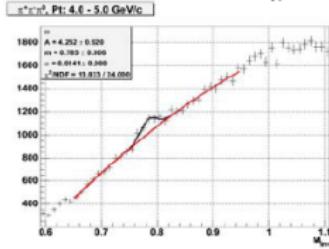
p+p @ 200 GeV
 $\omega \rightarrow \pi^0\pi^+\pi^-$



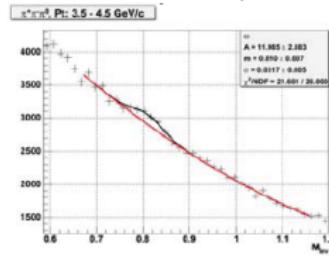
$\omega \rightarrow \pi^0\gamma$



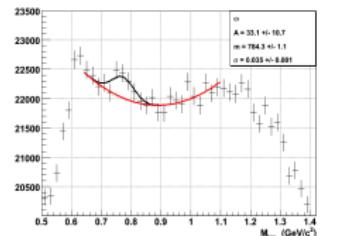
d+Au @ 200 GeV
 $\omega \rightarrow \pi^0\pi^+\pi^-$



$\omega \rightarrow \pi^0\gamma$

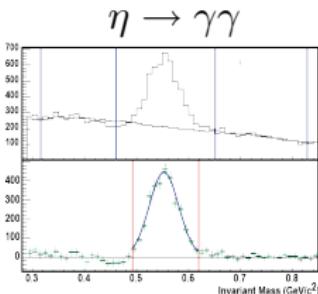


Au+Au @ 200 GeV
 $\omega \rightarrow \pi^0\gamma$

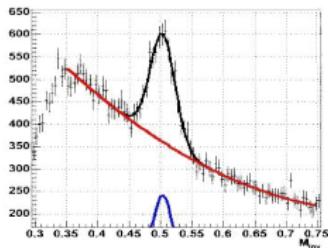


η and K_S^0 meson raw peaks

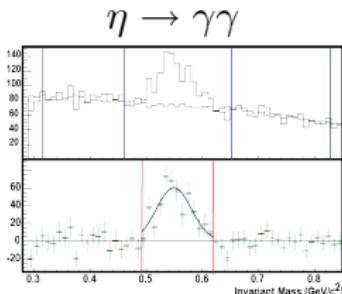
p+p @ 200 GeV



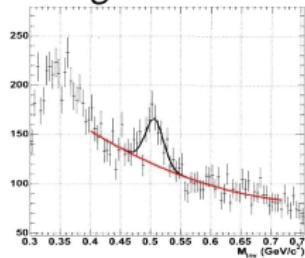
$K_S^0 \rightarrow \pi^0\pi^0$



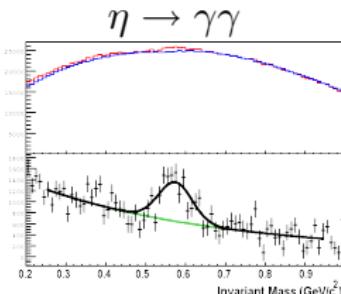
d+Au @ 200 GeV



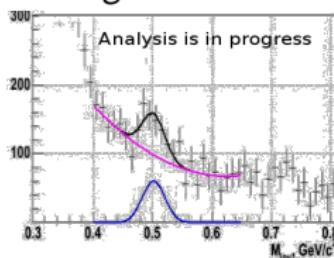
$K_S^0 \rightarrow \pi^0\pi^0$



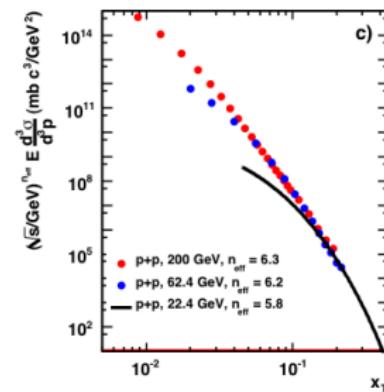
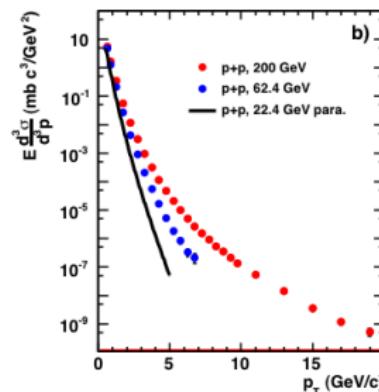
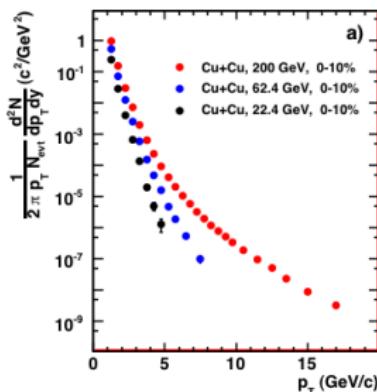
Au+Au @ 200 GeV



$K_S^0 \rightarrow \pi^0\pi^0$



π^0 spectra in Cu+Cu at 22.4, 62.4 and 200 GeV



p+p reference measured at 62.4 GeV and 200 GeV by PHENIX

p+p reference at 22.4 GeV:

World data for $21.7 < \sqrt{s_{NN}} < 23.8$ GeV rescaled to 22.4 GeV
Fit describes data within 25%

Scaling in $x_T = 2p_T/\sqrt{s}$: Pion production dominated by hard scattering for $p_T > 2$ GeV at all three energies